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Gendered opportunities for improving soil health

A conceptual framework to help set the research agenda

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ABSTRACT

Healthy soils play a critical role in supporting agricultural productivity, climate change mitigation and resilience, and a range of ecosystem services. Degraded and poorly responsive soils cover large areas of Africa and represent the majority of poor farmers' fields in certain regions. While there are hundreds of technical options for improving the sustainability of land management and preventing or reversing degradation, there are many sociocultural, institutional, economic, and policy barriers hindering their adoption at large scale. At the same time, there is an emerging consensus within the international development community that gender equality and women's empowerment are both an end in themselves and an important means for achieving a range of economic and social development objectives such as improved food security, child nutrition and education, and women's health. Yet, gender inequality remains a wicked problem, whose deep-seated socio-economic and ideological causes are difficult to recognize and address, and which require context- and culture-specific understandings and approaches, involving multiple stakeholders with different and sometimes conflicting interests and different positions within power hierarchies. There is an urgent need to make more rapid progress on restoring and sustaining soil productivity and ecosystem functions and also to leverage soil health management for progress on gender equality. While there are important interconnections between soil health and gender equality and empowerment, these are seldom recognized, and have not been addressed in a coherent or concerted manner. In this study, we have reviewed relevant gender literature and proposed a conceptual framework to help illuminate important gender considerations for soil health and land management. These considerations are essential for identifying gender-based constraints, opportunities, and unintended consequences in promoting soil management technologies. Moreover, the application of the framework can help guide in priority setting with respect to where gender-responsive interventions are essential. We make several recommendations for setting priorities for gender-soil health research.

Keywords: soil health, gender equality, sustainable land management (SLM)

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1. INTRODUCTION

Recent decades have seen an increasing recognition that healthy soils play a critical role in supporting agricultural productivity, climate change mitigation and resilience, and a range of ecosystem services (Lal 2004; Govaerts et al. 2009; Tonneijck et al. 2010; Smith 2012; Koo et al. 2016, Nkonya et al. 2016), linking strongly to the achievement of several Sustainable Development Goals (Keesstra et al. 2016). Soil health, also referred to as soil quality, is defined as the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans (USDA-NRCS 2017). Of the three pillars of ecological intensification proposed by Cassman (1999), yield potential, soil quality and precision agriculture, the second is the most urgent in Africa (Tittonell and Giller 2013). Other researchers have broadened the soil fertility focus to define soil health as an integrative property that reflects the capacity of soil to respond to agricultural intervention, so that it continues to support both the agricultural production and the provision of other ecosystem services (Kibblewhite, et al. 2008). Whatever the case may be, scientists warn that soil degradation "is a pervasive, systemic phenomenon occurring in all parts of the world", and "an urgent priority in order to protect the biodiversity and ecosystem services that are vital to all life" (IPBES 2018).

At the same time, there is an emerging consensus within the international development community that gender equality and women's empowerment are both an end in themselves and an important means for achieving a range of economic and social development objectives such as improved food security, child nutrition and education, and women's health (Kabeer 2001; Quisumbing 2003; Smith et al. 2003; World Bank 2011; van den Bold et al. 2013; Corroon et al. 2014; Gates 2014; Sraboni et al. 2014; Cunningham et al. 2015; Malapit and Quisumbing 2015; cited in Johnson et al. 2018). This recognition is reflected in Sustainable Development Goal (SDG) 5, 'Achieve gender equality and empower all women and girls', which is considered integral to all dimensions of inclusive and sustainable development[1]. Yet, gender inequality remains a wicked problem, whose deep-seated socio-economic and ideological causes are difficult to recognize and address, and which require context- and culture-specific

[1] UNWomen: http://www.unwomen.org/en/news/in-focus/women-and-the-sdgs/sdg-5-gender-equality

understandings and approaches, involving multiple (male and female) stakeholders with different and sometimes conflicting interests and different positions within power hierarchies (Alford and Head 2017).

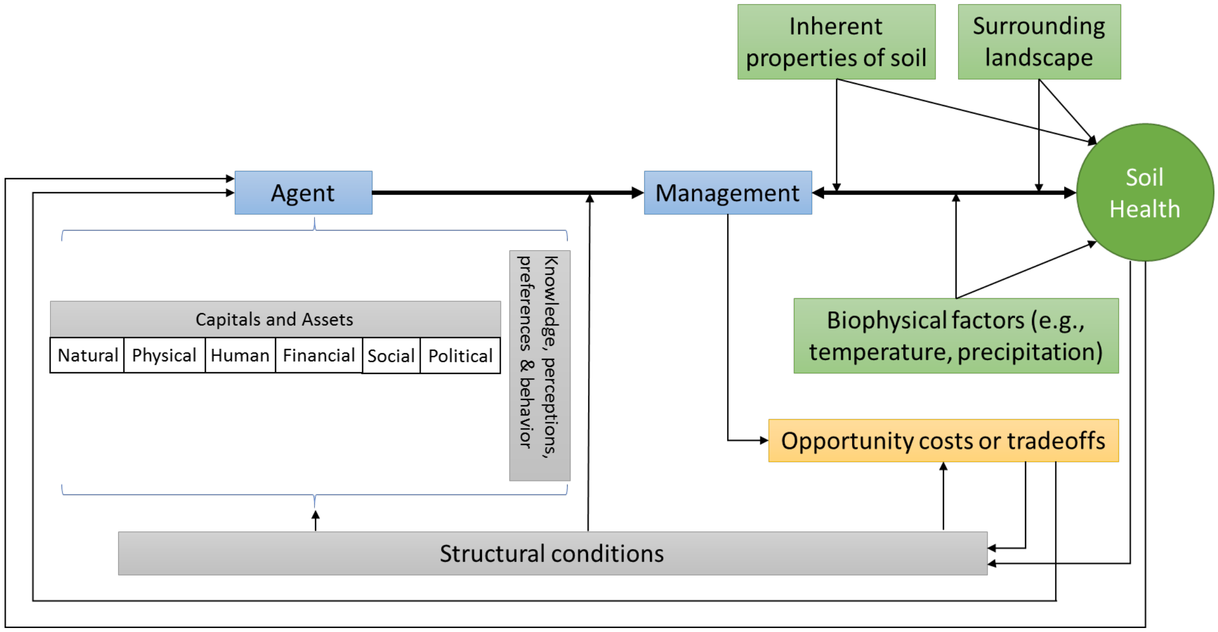
While there are important interconnections between soil health and gender equality and empowerment, these are seldom recognized, and have not been addressed in a coherent or concerted manner. This study contributes to filling that gap by proposing a conceptual framework for understanding the interlinkages between gender and soil health. The remaining of the paper is divided into three parts. We begin by laying out the general determinants of soil health, our outcome of interest in this case, using a generic framework. We then incorporate important gender considerations into this framework, which shows concern for equity aspects of soil management, rather than only soil health, as an outcome. In doing so, we assess the existing literature on soil health and gender in agriculture with the aim of identifying consensus, disparities, and gaps in evidence. Lastly, we draw implications of our findings on research priority setting with respect to where and when gender considerations are important for efforts to enhance soil health in a smallholder agricultural context. We make recommendations for how research and development projects can better design soil health interventions by considering gender, and how soil health initiatives designed with an equity perspective can lead to greater gender equality.

2. DETERMINANTS OF SOIL HEALTH: A GENERIC FRAMEWORK

Drawing from the extensive discussion of factors influencing soil health in the soil science and land degradation literature (e.g., FAO 1994; Kibblewhite, et al. 2008; Nkonya et al 2016; USDA-NRCS 2017), we highlight four key factors that drive soil health: *inherent properties of soil, surrounding landscape, biophysical factors*, and *management practices* (hereafter referred to as *management*) (Figure 1). Of these factors, only management is likely to be gendered but inherent properties of the soil, surrounding landscape, and biophysical factors are also important conditions underlying the extent to which the health of soils responds to management choices.

The USDA-NRCS (2017) describes that soil has both inherent and dynamic properties, or qualities. *Inherent properties of soil* are defined by the combinations of mineral particles, organic matter, water, and air present in soil (McCauley et al. 2005). They do not change easily and are a function of the soil's formation over millennia. Inherent properties underline a soil's natural ability to function. For example, sandy soils drain faster than clay soils. In contrast, the dynamic quality of soil is how soil changes depending on how it is managed (see *Management* in Figure 1). As noted in Tittonell and Giller (2013), the fertilizers that are generally available simply do not work on degraded soils, and thus substantial investment to build soil organic matter is needed to restore such soils to a responsive state. Their analysis suggests that an important fraction of the yield gap in African smallholder agriculture may be reduced through proper agronomic management (planting dates, spacing, cultivars, early weeding, etc.) even when fertilizers are not applied.

Figure 1. Generic relationship between agent and soil health.



Source. Authors.

Surrounding landscapes refer to landscape properties, such as land mosaics composition, spatial configuration, and biodiversity. These interact with soil ecosystems and affect soil health (Mäder et al. 2002; Bennett et al. 2006). Agricultural landscapes are made up of mosaics of diverse land uses (Bennett et al. 2006). An agricultural soil system is a subsystem of the agroecosystem, and the majority of its internal functions interact in a variety of ways across a range of spatial and temporal scales (Kibblewhite et al. 2008).

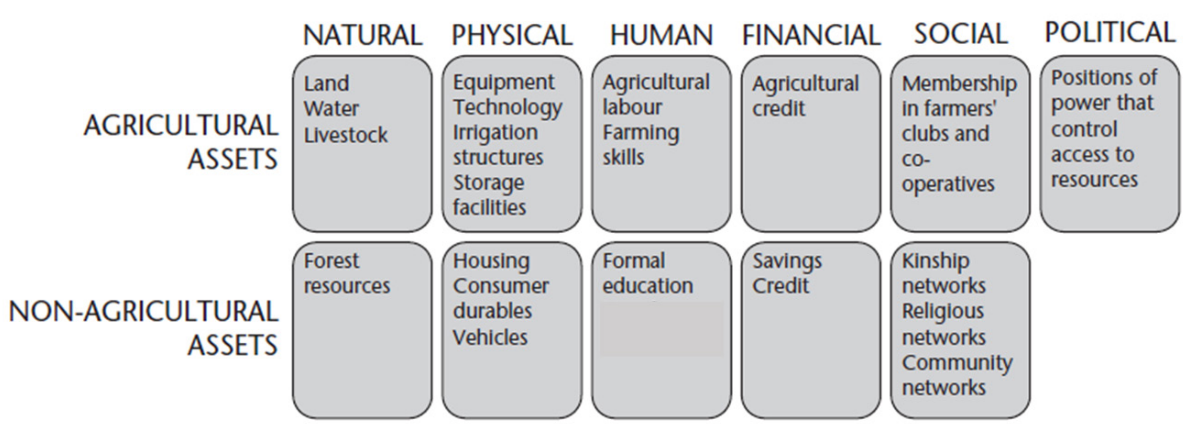
Biophysical factors such as precipitation and temperature affect soil health directly and indirectly. Climate change has complex and non-linear impacts on soils and thus predicting the composite effects of climate change on soils is extremely difficult (Smith et al. 2008). Keesstra et al. (2016) note that, in general, increasing temperatures will tend to increase decomposition, but this will be limited where soils become very dry – so changes in temperature and precipitation can have additive effects, or may work in opposite directions. In addition, increasing temperatures can also increase plant production, thereby increasing carbon inputs to the soil.

While each of the above three factors affects soil health directly, *inherent properties of the soil*, *surrounding landscape*, and *biophysical factors* also influence the extent to which soil health responds to *management* choices. Soil management choices can affect the amount of soil organic matter, soil structure, soil depth, and water and nutrient holding capacity, which affect soil function and soil carbon stocks (all captured under the rubric of 'soil health' in Figure 1). Whereas the biophysical aspects influencing soil health have been widely studied, social considerations—including their gender dimensions—which influence management practices are similarly important and call for better consideration (Ayuk 2001).

Figure 1 also draws attention to *agents,* or units of decision-making, such as a farm household or individual. Agents are enabled or constrained by the availability and use of *capitals and assets* (the physical and immaterial resources they have at their disposition to make a living, or for the purpose of this paper, to manage their land), and influenced by their *knowledge, perceptions, preferences and behaviour*, to make *management* choices that affect soil health outcomes.[2]

Following Meinzen-Dick et al. (2014b), our framework categorizes different forms of asset holdings as six key capitals: natural, physical, human, financial, social, and political capital. Other recent studies distinguish between agricultural and non-agricultural assets (Quisumbing et al. 2015). Djurfeldt (2018) presents a schematic representation of how the distinction between agricultural and non-agricultural assets can be reconciled with the six key capitals (Figure 2).

Figure 2. Agricultural and non-agricultural assets, or 'capitals'.



Source: Djurfeldt (2018).
Note: Examples of assets are not exhaustive.

[2] In the context of this study, *Agent* refers to smallholder households. We do not consider national or global entities that invest in soil management as a climate change mitigation option.

Interacting with and underpinned by the six capitals, *knowledge, perceptions, preferences and behaviour* shape soil *management* decisions. It has been well documented that farmers' time and risk preferences are among the important behavioral drivers of investment decisions concerning soil health. Probably less recognized is the fact that farmers often have a clear focus and detailed knowledge about soils. For instance, Baker et al. (2015) find that, while researchers went into the mapping and modelling process focused on land use and crop type, community participants in Ethiopia viewed the landscape through a soil lens with detailed local terminology, understanding, and descriptions of the different soil types and fertility limitations.

Management choices often induce *opportunity costs*. For instance, increasing the application of compost (organic fertilizer) to improve soil health (Ouédraogo et al. 2001) could reduce the availability of animal waste-based biofuel (e.g., cow dung), resulting in switching to alternative fuel sources. *Trade-offs* may also arise across different aspects of sustainable land use. In the case of cow dung being diverted away from household fuel purpose, for instance, improving soil health through increased use of compost may lead to greater demand for firewood, adding pressure to forest resources. Although not explicitly represented in the diagram, temporal and spatial scales are important considerations in assessing *trade-offs* due to externalities imposed on future generations or off-site populations or communities.

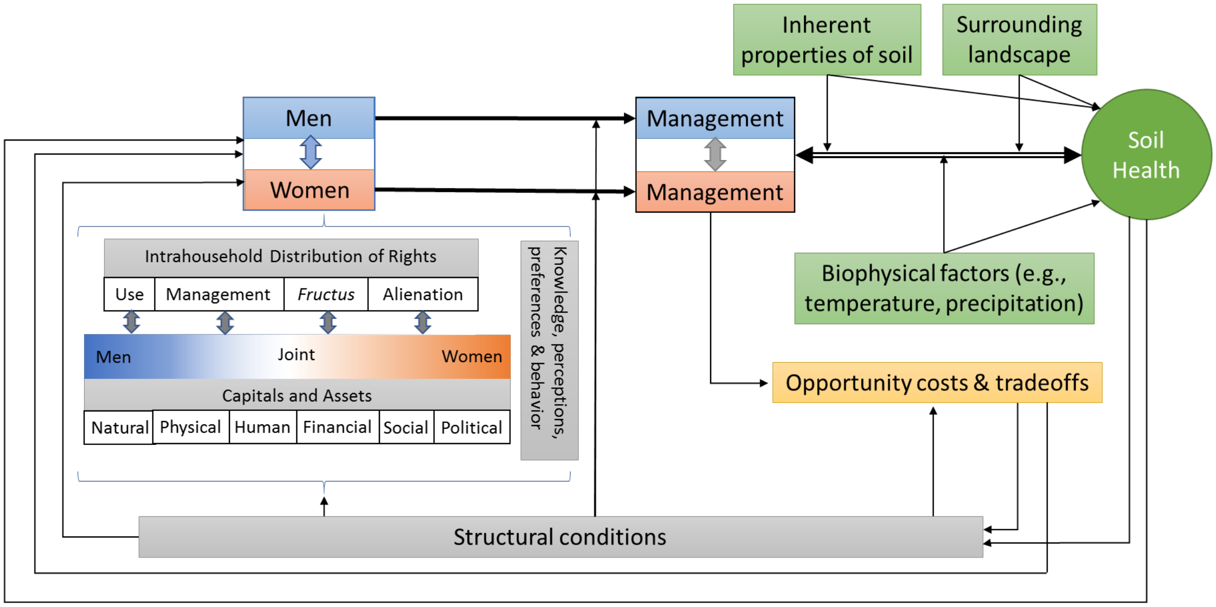
As opposed to *capitals and assets*, *knowledge, perceptions, preferences and behavior*, which are considered individual or micro-level conditions in this framework, *structural conditions* are macro-level conditions under which *agents* make *management* choices. These macro-level factors include the specific legal, moral, and societal conditions that structure farmers' access, use, control, and ownership of assets (Quisumbing at.al. 2014). In addition to underpinning *capitals and assets*, *structural conditions* in our framework also shape and affect the *knowledge, perceptions, preferences and behaviour* of the *agents* making land management decisions, and thus their adoption of soil *management* practices, and associated *opportunity costs or trade-offs*. Take institutional and market conditions as an example. Poorly defined property rights and limited access to credit and insurance markets often prevent the poor from making significant investments in soil health; and when they do make such investments, these need to yield quick results (World Bank 1992).

Self-reinforcing behaviors, or feedback loops are an important feature of human-nature coupled systems. Our stylized framework illustrates three key feedback loops, but the illustration is not meant to be exhaustive. First, the lack of investment of farmers' labor in agriculture, as documented for African smallholder agriculture in Tittonell and Giller (2013), may be caused by a lack of agricultural inputs required to allow efficient returns to labor, in a context where local soil degradation requires large investment to achieve a response to inputs of fertilizer and labor – a so-called 'poverty trap' (Carter and Barrett, 2006; Marenya and Barrett, 2007) – rather than due to lack of knowledge (Tittonell and Giller 2013). This lack of response (in time or magnitude) to *management* in soil health which in turn disincentivizes *management* is captured by the double arrow between *management* and soil health. Second, the outcome of *management* in terms of soil health will affect the underlining micro and macro conditions *agents* face, which in turn affect the future *management* choices *agents* make. An example of this feedback loop is the so called "poverty-land degradation" trap, i.e., the downward spiral of poverty leading to degradation leading to more poverty (Durning 1989; Duraiappah 1996; FAO 1999). In the third feedback loop, *management* decisions result in various *opportunity costs or trade-offs*, which contribute to shaping the micro and macro conditions that in turn influence *agents*' future *management* decisions. For example, the household fuel switch and firewood demand example given above could potentially lead to tightened regulation restricting resource users' access to forest.

3. GENDERED OPPORTUNITIES AND CONSTRAINTS FOR IMPROVING SOIL HEALTH

There are several ways in which revising the above framework through a gender lens can improve understanding of the processes underlying soil health, as well as of how soil health affects gender relations. It has been well recognized that the household is not the appropriate unit of analysis when studying households with both jointly and separately managed plots of land because different household members have different access to and control of the six capitals described above (Doss 2001). Moreover, the literature has shown that men and women commonly have different preferences and face different types and severity of constraints to adopting technology (Doss 2001; Doss and Morris 2001; Ragasa et al. 2013). Gendered differences in each of the six types of *capitals and assets*, including but not limited to land tenure security and access to and control over resources, result in gendered opportunities and constraints for improving soil health and land management, as well as gender-differentiated perceptions about ecosystem services and behaviour regarding resource use and agricultural technology adoption (Doss and Morris 2001; Meinzen-Dick et al. 2014a, 2014b, and 2017; Quisumbing and Kumar 2014; Quisumbing et al. 2014 and 2015; Doss et al. 2015; Kieran et al. 2015 and 2017; Johnson et al. 2016; Kristjanson et al. 2017). Therefore, gender-disaggregated analysis is essential to informing the design, implementation, and evaluation of soil health programs. Building on the generic framework presented in Figure 1, this section adds analytical purchase to the conceptual framework by incorporating important gender considerations.

Figure 3. Gendered relationship between agent and soil health.



Source. Authors.

The relationships between gender-specific constraints (for example, regarding women's typically more limited asset holdings and access to production inputs and rural services) and technology adoption have been studied extensively. It has been well documented that women in developing countries are generally less-endowed with income and other forms of capital and have less access to formal education, technical information and other services than men (Rocheleau et al.1996; Peterman et al. 2014). Consequently, women's ability to invest in land improvement tends to be lower than men's, which could lead to more degraded female-owned lands than men's (Peterman et al. 2014; Samandari 2017; World Bank, FAO and IFAD 2008). Norms that influence land inheritance patterns and limit women's access to the most fertile lands as well as labor constraints also influence the quality of women's lands compared to men's (FAO 2011).

Although members of households do not necessarily share the same preferences or pool their resources to improve overall welfare (Alderman et al. 1995; Doss 1996; Doss et al. 2014), when household members work together on multiple agricultural activities, some degree of joint use and decision making over assets is common (Theis et al. 2018). Hence, Meinzen-Dick et al. (2011) describe a spectrum of jointness and separateness within the household. For instance, women may benefit from a technology (physical capital) or asset even if they do not have recognized ownership (Njuki et al. 2014, cited in Theis et al. 2018). This concept of joint-separate continuum runs throughout the framework, as it relates to capital endowments, as well as to *management* choices and practices, which may be made and executed separately or with some degree of discussion, agreement, and shared labor among household members. We thus introduce a colored spectrum of "*Men – Joint – Women*" to indicate the varying level of jointness and separateness between men and women over ***capitals and assets*** and decision-making (Figure 3). The two-way arrows between "***Men***" and "***Women***" and between the two linked "***Management***" boxes in the diagram also convey the message that jointness and negotiations between men and women may take place in resource use/control and decision-making.

In a study bringing gender dimensions into discussions of soil health management, Goldman and Heldenbrand (2002) find that the three main management practices they identify as leading to more fertile soils (longer fallow periods, and application of organic and chemical fertilizers) have gendered patterns in Southeastern Uganda. Given the small size of women's landholdings, significantly fewer women (15%) in their study than men (38%) practiced any fallowing. Women farmers also had less cash available than men to purchase chemical fertilizers. With respect to organic fertilizers (manure, compost, mulching and household refuse), poor farmers had insufficient livestock units to produce an adequate supply of manure, and labor constraints limited its application. These limitations were particularly acute for women farmers and female-headed households, which had fewer livestock units and the least amount of available labor. These constraints in natural, physical and financial capital resulted in an inability to replenish soil fertility amid a loss of nitrogen due to erosion, intensive harvesting, and leaching (see Box 1 for a richer gender analysis of fertilizer use).[3]

Because of the central role they play in shaping soil management practices, we discuss gendered labor (human capital) and land tenure (natural capital) patterns in greater detail than the other capitals below. The labor issue has two interrelated dimensions. First, rural women typically experience 'time poverty' because their daily activities are time- and labor-intensive. In general, these activities include

[3] Evidently, gender is not (and was not in the study) the only factor influencing the adoption of organic and inorganic fertilizer. Adoption must be understood within broader limitations experienced by sub-Saharan African smallholders, each of which embeds gender inequalities. These include weak access to (input and output) markets, low mechanization and high labor requirements, and limited capital to purchase inputs, among other constraints (Tittonel and Giller 2013).

agricultural production and trade, but also 'reproductive' activities, which maintain the household – for example, caring for young, elderly or sick household members, cooking, cleaning, and collecting firewood and water. Moreover, for several reasons, including norms that associate new technologies with men, women typically have less access than men to labor-saving technology (Grassi et al. 2015). For example, Grassi et al. (2015) note that even though the gender division of labor is not always clear cut, in general men have easier access to animal draught power and mechanization for ploughing and clearing of land, while women's work tends to be more manual, tedious and labor-intensive. The result is that rural women spend more time than men working to produce less. This has broad implications for their family and productive life and weighs on the choices they are able to make, including the choice to dedicate time to leisure. Hence, Grassi et al. (2015) recommend labor-saving technologies, practices and services that can relieve women's work burden in agriculture. They advocate for collective access to and management of technology and collective services provision as an entry point for reducing women's work burden. Moreover, norms that maintain women's responsibilities within the household will need to be challenged to redistribute labor burdens and enable men to share in those responsibilities (e.g. UN Women 2014).

The second, interrelated consideration with regard to gendered labor patterns is that women and (senior) men do not have the same ability to control their own labor and that of others. As Doss (2001) finds, in customary systems in most countries in sub-Saharan Africa, men have control over women's labor, but not vice versa. Kazianga and Wahhaj (2013) show that in Mali, male household heads have higher agricultural yields than other household members (including junior men) because they can command the labor of other household members on household plots. Similarly, Collins and Frotz (2013) show that labor availability is even more important than fertilizer use in determining productivity differentials between plots managed by women and men in Mali. In their study, gender gaps in productivity decreased when there were more women in the household who could share labor on women's plots.

Labor constraints have implications for women's adoption of labor-intensive land management practices (Ragasa 2012), such as integrated pest management (IPM); biological nitrogen fixation technologies; and conservation (zero) tillage practices (World Bank, FAO and IFAD 2008; Quisumbing and Pandolfelli 2009). Labor shortages are reflected in the inability to make full use of conservation farming techniques on female-managed farms (FMFs), especially in the short term (Djurfeldt and Hillbom 2016). In fact, Djurfeldt (2018) identifies the shortage of labor as the distinguishing feature of farms managed by women in a study carried out in Malawi, in which women who were heading their own households attributed the loss of male labor to a gradual loss of soil fertility over time.

When labor-intensive soil management approaches are adopted in household production systems, they may also disadvantage women by increasing their labor burden. As a case in point, Giller et al. (2009) show that conservation agriculture interventions aimed at reducing the use of herbicides tend to increase women's labor burdens disproportionally as they are responsible for the labor-intensive task of weeding. Women may also fail to benefit from conservation agriculture interventions if they target labor practices which are traditionally masculine activities (e.g., weeding with oxen), as this complicates their implementation in women's fields.

Secure access and control over land plays another important role in determining land *management* decisions. As noted in Meinzen-Dick et al. (2017), secure land rights are expected to increase agricultural productivity through greater investments on the land, as incentives to invest are greater with the knowledge that land will remain one's own in the long term. Moreover, where rural credit institutions are available that use land as collateral, secure tenure can facilitate access to credit for investment and thereby investments in land. Increased access to credit may also affect non-agricultural livelihoods by facilitating diversification into non-agricultural livelihoods and access to land rental and sales markets. Meinzen-Dick et al. (2017) also note that, while land use rights are needed to adopt any agricultural production technologies, control rights and security of tenure may affect the adoption of longer-term investments, particularly NRM practices (Besley, 1995; Meinzen-Dick and Di Gregorio, 2004). For example, Kazianga and Masters (2002) and Etongo et al. (2018) find that land rights are a key determinant of farmers' soil conservation practices in Burkina Faso. Yet, despite a recent resurgence of literature comparing the productivity of men and women farmers (see Doss, 2017), almost none of it considers the impacts of women's land rights, as the systematic review of the literature by Meinzen-Dick et al. (2017) reveal. They note that the literature has shifted away from comparing male and female headed households to analyses of the productivity of plots farmed by men and women, but the land rights themselves, and tenure security specifically, are not generally considered (e.g., Peterman et al. 2011; Slavchevska 2015; Oseni et al. 2015; Kilic et al. 2015; Aguilar et al. 2015; Ali et al. 2016; de la O Campos et al. 2016). Several authors (Gray and Kevane 2001; Meinzen-Dick et al. 2017) also note that the relationship between land rights and soil management is bidirectional: investments in soil fertility are also investments in the land and can have positive feedback effects on land rights by increasing tenure security. Moreover, in a context of tenure insecurity, improvements in soil fertility can affect gender relations and rights to land, as men may confiscate women's enriched fields to grow their own crops (Millar et al. 1996, cited in Quansah et al. 2001).

Property rights policies and laws (*structural conditions*) are essential to enhancing women's control of land and income, but cannot, of themselves, create gender equal opportunities to adopt certain *management* practices. Policy makers must also address other drivers and constraints that women face in adopting and benefiting from technologies. Theis et al. (2018) argue that it is essential to identify different rights of different people within the household beyond "ownership" or "control" of assets in order to understand the intrahousehold dynamics with respect to an asset. They identify a "bundle of rights" over a resource or asset (which can include technologies, which we use as an example below), drawing from two bodies of literature on gender and assets, and property rights (Schlager and Ostrom 1992; Benjaminsen and Ba 2009): 1) *Use* rights refer to the right to use resources, including to physically operate a technology, 2) *Management rights* to the right to make decisions on what investments to make in the land or how, when, and where to apply the technology, 3) *Fructus* as the right to control outputs and profits generated by the use of the resources, and 4) *Alienation rights* as the right to sell, lease, or give away the resources.

To help us understand the ways household members, both women and men, access and control the assets they need—including but not limited to land—to manage soil health, we apply these four bundles of rights under the rubric of intrahousehold distribution of rights, following Theis et al. (2018). Many discussions focus on women's "access" to land, which is a use right. While use rights are certainly important, by themselves they are often insufficient, especially when women depend on men for access to land or equipment. For example, if women have access to plough or transport equipment only after men, their operations may not be as timely, resulting in loss of productivity.

Management rights are important because they convey authority to make decisions about how to use the technology, or about investments in the land. In particular, those with insecure tenure are prohibited from planting trees because this is seen as too much of a claim on the land. Fructus rights that ensure that women will benefit from any use or income from the resource are crucial to providing incentives for investing time, labor, money, or other resources. Alienation rights are often argued to provide longer-term incentives, such that the holder of the rights can benefit from any appreciation in the value of the land as a result of improved soil fertility. Even if a woman does not intend to sell or rent out her land, it is important that she have the right to prevent others from alienating her land without her approval. Otherwise, she has little incentive to invest in long-term improvements in the land. Although, as noted above, most studies on the link between land tenure security and investment do not look at intrahousehold distribution of rights, Ali et al. (2014) found that land certification which increased tenure security in Rwanda has a particularly strong effect on women heads of households' investment in bunds, terraces, and check dams for soil conservation. In Uganda, Deininger et al. (2008) report that both the legal status of land and knowledge of land rights affects adoption of tree planting and soil conservation, particularly for female headed households.

Aside from and interacting with gender-differentiated *capitals and assets* and their distribution within the household, *knowledge, perceptions, preferences and behaviour* are known to differ between men and women and to influence *management* decisions. For example, Villamor and van Noordwijk (2016) find that men and women in an experimental role-playing game setting in Indonesia differ in their willingness to assume risks with respect to land use choices, suggesting that gender-specific land use decisions and preferences should be considered in managing landscapes and associated ecosystem services. Similarly, women and men can have different preferences for time discounting. In the Villamor and van Noordwijk (2016) study, participating women had a greater tendency than men to seek immediate benefits (e.g., financial benefits from converting current land uses to monoculture systems) over other ecosystem services (e.g., carbon sequestration) that occurred over the long term.

While patterns of gender-specific *knowledge, perceptions, preferences and behaviour* regarding land management and technology adoption are context-specific, studies have identified various factors underlying gender differences. In general, local agroecological knowledge (human capital) differs between gender groups due to differences in socially ascribed roles in production. In a review article, Elias (2016) demonstrates that women and men may be responsible for growing different crops, farming in different zones, completing different phases of the cultivation cycle, or performing the same tasks using different tools. For example, for a given crop, men may contribute to land preparation and pest management, and women to sowing, weeding and threshing, with other activities being performed by both genders (e.g. Doss 2002; Orr et al. 2016). The knowledge, perceptions, and preferences they acquire, including with respect to soil management techniques, will thus differ (Elias 2016). As a case in point, Zuniga et al. (2010) demonstrate gender differences in farmers' knowledge about the links between soil organic content and the occurrence and variety of earthworms in the Brazilian Atlantic Forest. They find that women were more knowledgeable about worms found in gardens, but men more proficient in identifying the potential usefulness of worms as indicators of soil quality, soil restoration and transformation of organic matter. Likewise, Frausin et al. (2014) demonstrate the role that gender-specific knowledge has played in configuring carbon-rich fertile soils in Liberia and Sierra Leone. They show that in fulfilling their gender-ascribed roles and responsibilities, women have shaped the soil landscape. Their cultural practices and preferences regarding the use of organic matter as fertilizer have resulted in carbon-rich fields. In conclusion, both Zuniga et al. (2010) and Frausin et al. (2014) argue for participatory biodiversity conservation and soil management initiatives that take local, gendered knowledge into account.

In addition, access to information acquired through formal, public channels, tends to be gender differentiated (Peterman et al. 2014). Based on a review of literature and synthesis of 35 case studies on gender and institutional dimensions of agricultural technology adoption, Ragasa (2012) shows that women farmers generally have lower levels of formal education, which affects their understanding and adoption, especially if the technology requires use of more technical and intensive knowledge. In many cases, social and cultural barriers, such as the perceived inappropriateness of women interacting with male extension officers, and time poverty are major constraints for women in acquiring information through trainings. Women are often excluded from formal and informal institutions that disseminate land management and soil conservation practices. For example, Ogunlana (2004) reports that in Nigeria, meetings with extension agents about alley farming were held at times that were inconvenient for them, given competing household responsibilities. Studying diffusion of agricultural information within social networks in Mali, Beaman and Dillon (2018) suggest that if network structures exhibit a tendency for central nodes within the network to be of only one gender, then the diffusion of information through social networks may reinforce existing gender informational inequality. Nkedi-Kizza et al. (2014) find a bias against women in agricultural extension and information on new fertilizing technologies, which, combined with women's lack of access to credit and financial resources, can account for lower yields and present difficulties when implementing soil fertility enhancing interventions. More restrained opportunities for participation and leadership in groups and organizations limit women's ability to use these platforms and avenues for consultations and information-sharing with other actors, including extension agents and researchers (Ragasa 2012). Bernier et al. (2015) found that in their study areas in Kenya, women were less likely to be aware of many climate-smart agricultural practices (many of which are designed to improve soil health), but that information from religious groups had more of a positive effect on awareness than information from farmer organizations or agri-service providers.

It is worth noting that boiling down household management decision-making to men and women, while adding nuance and perspective than an understanding of the household as a heterogeneous entity, remains a simplified, binary approach to understanding complex decision-making issues. The social positions individuals occupy are a function of complex identities shaped by the intersection of gender with generation, marital status, and other features of a person's identity. The concept of intersectionality – or how multiple identities in a given person interact with one another and with marginalizing or empowering structures, norms and narratives – allows us to move away from static, binary and simplistic conceptualizations of gender (Hankivsky 2014; Colfer et al. 2018). The intersection of multiple identities "contribute[s] to unique experiences of oppression and privilege", which are expressed in context-specific ways (AWID 2004, p1). These positions affect bargaining and power dynamics within and beyond the household, and shape the choices made by individuals and households. For example, in Nepal, both men and women who belong to an upper social caste used chemical fertilizers, but women and men from lower castes differed in fertilizer application, with women being more likely than men to use farmyard manure (Raya 2013). As noted above, women in male-headed households and women heads of household also face different challenges (e.g., Djurfeldt 2018). Hence, it is necessary to look beyond gender alone to understand resource use opportunities, decisions, and patterns.

In Figure 3, context, particularly *structural conditions*, influences the ways stakeholders interact with soil and the types of *management* strategies they use. These structural conditions include formal institutions, such as laws and policies, formal credit facilities and extension systems, as well as information institutions, such as local prices for inputs and outputs and norms that shape what is considered appropriate behaviour for women and men in a given society. Men's and women's relationship to nature is rooted in their material reality, which are themselves shaped by gender, socio-economic status, and other factors of social differentiation (Quisumbing et.al. 2014). Cultural and social norms that influence women's access to and control over natural resources are highly contextual, varying across place (e.g. villages) and time (Djurfeldt 2018). Their impacts on gender roles, behaviors, access to assets and rural services, such as trainings, are also dynamic in nature, often demonstrating a self-enforcing or feedback loop relationship. For instance, in recent years, shifts in gender-specific productive roles have been associated with land-use changes in Indonesia (Villamor et al. 2015). Villamor and van Noordwijk (2016) note for example that in the lowland areas of Jambi province, where rice fields were converted to oil palm and rubber monocultures, women are now involved in agricultural activities that were once dominated by men (e.g., land preparation, fertilizer application, etc.). Gradual changes have also been observed in women's roles in irrigation management and/or Water User Associations in Nepal, driven by large scale male migration and the so-called feminization of agriculture, despite resistance rooted in traditional gender norms (Zwarteveen et al. 2010).

Opportunity costs and trade-offs associated with *management* can also differ for men and women. For example, as noted above, the adoption of organic compost for soil fertility management could mean there is less animal waste-derived cooking fuel available. As a result, women, who are mostly responsible for cooking, may have to reply more on other fuels. In the case of fuelwood, they may have to spend more time collecting fuelwood and may suffer from health issues related to indoor air pollution related to cooking with fuelwood. Unless alternative fuels are available, another trade-off, deforestation and a potential decline in ecosystem services provided by the forest will also have gender-differentiated effects. Stevano et al. (2018) note that trade-offs can be complex and unpredictable and depend on a range of factors. For example, women's employment in agriculture may not always reduce time for childcare, especially when there are other people in the home who take on this responsibility (Kadiyala et al. 2014, cited in Stevano et al. 2018).

In Box 1, we illustrate some of the key points of the gender framework (Figure 3) drawing on the example of a soil health intervention: organic composting. The example is not meant to comprehensively cover all aspects of the technology, but rather to illustrate how gender affects the different technological elements of a soil health intervention in myriad ways.

Box 1: Improving soil health with organic compost

Organic compost has been promoted as an important approach to improving soil health (FAO and ITPS 2015; Beaman and Dillon 2014; Rivero et al. 2004). Increasing soil organic matter through the incorporation of organic compost can improve soil water holding capacity and increase levels of soil carbon, which in turn improves long term fertility, as well as providing available nutrients to crop plants (Ouédraogo et al. 2001; Beaman and Dillon 2014). Unlike inorganic fertilizers, organic compost is a low-cost option that also helps to build up fertility in soils over time (Ouédraogo et al. 2001; Beaman and Dillon 2014). Improving soil organic matter has become a central tenet of soil management within climate smart agriculture, and composting is a proven strategy for boosting soil organic matter (FAO and ITPS 2015). Composting also forms part of sustainable intensification programs (Therialt et al. 2017).

Composting requires the combination of crop residues, animal manure, household residues, and ashes from fuel. The process of manufacturing and incorporation of compost into soil requires knowledge and expertise (Beaman and Dillon 2014). In addition, composting requires access to equipment for transporting, and access to crop residues and animal manure. Finally, manufacturing, maintaining, and incorporating compost into soil in farm plots require significant labor. These three elements -- knowledge and expertise, access to equipment, and labor-- are thus important requirements for adoption.

The literature on gender and the adoption of soil conservation technologies emphasizes the need for greater awareness of gender imbalances when disseminating knowledge to households (Quisumbing et al 2014; Beaman and Dillon 2014; Bernier et al 2015). Therialt et al. (2017) found that eliminating the gender bias in extension services, where men tend to be the first port of call for extension agents, is one of the key ingredients to improving the adoption of soil conservation practices such as composting. Bernier et al. (2015) emphasized the importance of considering gender in knowledge dissemination for greater awareness and subsequent adoption of soil improving practices like composting and mulching.

Access to animal manure, crop residues, and machinery for transporting compost is vital for an agent to manufacture and apply it to their fields. When it comes to *capitals and assets*, there is no clear-cut relationship between household wealth and organic compost adoption. Bellwood-Howard (2013) described a dilemma in Northern Ghana where the wealthy, who own transport assets, are not interested in using organic compost, whereas the less wealthy, who would have preferred the more "affordable" organic compost than commercial fertilizers, often do not have the means to adopt it, due to, for example, the lack of transport assets. It should be also noted that the quantity of organic household residues smallholders can draw on is typically limited (Quansah et al. 2001; Giller et al. 2009). Given that assets are not equally distributed across gender groups, women often face additional difficulties using fertilizer when this use hinges on access to other assets. For example, as noted above, women may have limited access to manure from livestock as they commonly own fewer livestock units than men (Quansah et al. 2001; Giller et al. 2009). This exemplifies the dual-necessity of raising awareness of the long-term soil health benefit of organic compost by all farmers and providing needed multi-pronged support to those who look to adopt the technology.

While gender inequalities limit women's ability to adopt certain soil management techniques, opportunities for women to participate in soil improvement practices, such as composting, can be carefully leveraged. For example, women may have greater access to crop residues through food processing duties and may have greater access to household food waste residues due to food provision duties. Stall-fed livestock may give women greater access to manure at the homestead. Women and young men in northern Ghana who had diversified into cash vegetable crops noted that compost-grown produce had a longer shelf-life and was better quality (Bellwood-Howard 2013). Manure application is considered a woman's job in some parts of the world. This gender norm has resulted higher organic fertilizer use in households with more women than in those with less female labor in certain regions of Ethiopia (Ketema and Bauer 2011).

Moreover, the production of organic fertilizer can involve heavier workloads, which are mainly borne by women (Halbrendt et al. 2014). Control over one's own labor and the ability to leverage outside labor is crucial to an agent's ability to effectively implement composting (Quisumbing and Kumar 2014). Nightingale (2006) finds that the adoption of some conservation practices can increase the time burden of already time poor individuals, at times without their consent. In some cases, men's control over their wife's labor may inhibit the ability of women to adopt conservation and soil fertility improvement practices on their own plots (Quisumbing and Pandolfelli 2010; Theriault et al 2017). Moreover, the use of household refuse or manure to fertilize soil entails an opportunity cost in terms of the foregone use of these materials as fuel or for feeding domestic animals. This opportunity cost largely affects women, as these tasks (cooking and feeding penned animals) generally fall within the sphere of women's responsibilities (Ayuk 2001).

Composting is a labor-intensive activity that does not necessarily provide immediate returns in terms of yield. However, it is shown to improve yields over time and can improve soil resilience in a context of climate change (FAO 2013; Beaman and Dillon 2014). Thus, the decision to adopt this practice is a long-term investment. Yet, more labor efficient means of improving soil health are required in labor-restricted scenarios. Interventions will need to address women's labor constraints through labor saving innovations and a redistribution of household labor if they are to generate gender-equitable opportunities.

4. IMPLICATIONS ON PRIORITY SETTING FOR GENDER-RESPONSIVE SOIL HEALTH RESEARCH

Degraded and poorly responsive soils cover large areas of Africa and represent the majority of poor farmers' fields in certain regions (Tittonell and Giller 2013). Improvements in land use and management are needed at a global scale to tackle interconnected global challenges of population growth, poverty, migration, climate change, biodiversity loss, and degrading land and water resources (Thomas et al. 2018). While there are hundreds of technical options for improving the sustainability of land management and preventing or reversing degradation, there are many sociocultural, institutional, economic, and policy barriers hindering their adoption at large scale (ibid.). There is an urgent need to make more rapid progress on restoring and sustaining soil productivity and ecosystem functions and also to leverage soil health management for progress on gender equality. In this study, we have reviewed relevant gender literature and proposed a conceptual framework to help illuminate important gender considerations for soil health and land management. These considerations are essential for identifying gender-based constraints, opportunities, and unintended consequences in promoting soil management technologies. Moreover, the application of the framework can help guide in priority setting with respect to where gender-responsive interventions are essential. We make several recommendations for setting priorities for gender-soil health research.

Long term and gender-disaggregated data and analysis

Long-term, gender-disaggregated data and in-depth, contextually rooted gender analyses are needed to understand how gender-differentiated challenges and opportunities a) respond to different interventions and incentives, b) require different enabling conditions, c) affect the distribution of outcomes, and d) evolve over time and across different stages of technology adoption, meriting the need to revisit and consider emerging issues.

Investments in agricultural innovations take time to capitalize, and all steps in a management feedback loop might be differentiated by gender and other social characteristics (Villamor et al. 2014). This is particularly true for soil management technologies and practices, whose success depends on the dynamic interactions between management and many slow-changing properties of the soil and surrounding landscape.

Prior studies have relied on the observed or self-reported level of adoption (typically a binary response of yes or no) collected through household surveys, whereas biophysical measurement of changes in agronomic conditions is rarely carried out beyond crop yields. Such an approach falsely assumes that a positive response to the adoption question is sufficient for women to implement effectively and benefit from adoption. In addition, factors beyond the control of individual farmers (such as changes in surrounding landscapes and climate) make the outcome of adoption less deterministic. Each phase of adoption - awareness, tryout, and continued adoption (Lindner et al. 1982) – presents particular challenges for different groups of women and men farmers (Theis et al. 2018). Hence, Theis et al. (2018) emphasize the importance of taking a long-term view to look beyond the initial adoption stage, and of bringing a nuanced understand of rights (which extends beyond the concepts of ownership and control) to evaluate intrahousehold distribution of impacts of adoption.

In conjunction with previous findings (Meinzen-Dick et al. 2014a; Meinzen-Dick et al. 2017), our review identifies as a major research gap the lack of empirical data disaggregating gender at the household level, or rather examining the gender roles of male and female decision makers within households with respect to land management. We also found a paucity of empirical studies that examine the household division of labor with respect to soil management. While most studies may capture the 'household head' and map ownership and assets to this person, they do not account for intra-household dynamics or the different tasks performed by men and women (Meinzen-Dick et al. 2014a; Meinzen-Dick et al. 2017). A review by Peterman et al. (2014) confirms that most of the limited studies that examined the gender-soil health relationship relied on household headship. Hence, many findings pertain to differences between so called male and female headed households. This is useful but can only provide limited view. Essentially, the role of gender in soil management in households which comprise both male and female spouses and the differentiated impacts of soil health on men and women in these households is left out. This calls for research that looks beyond household headship, at how intra-household resource and work allocation and decision-making affect soil management; and how soil health influences these processes in return.

Gender-disaggregated behavioral research is also needed to better understand why men and women make certain choices and how they respond to incentives or behavioral nudges. Villamor and van Noordwijk (2016) suggest that combining agent-based modelling with experimental games reveals behavioral patterns that are mainly beyond the assumptions of economic theory. The combination of methods and broader application of such combinations in the context of land-use decision making with an explicit gender dynamic dimension is still at a rudimentary stage and requires further development (Meinzen-Dick et al., 2014). Hybridization of tools and methods enhances the representation of the true complexity of human decision making (Villamor et al. 2011).

Integrated research approach

Our review has found that the conceptualizations of soil health has in many cases been limited to yield for agricultural production, which may not capture longer-term sustainability (Schulte et al. 2014; Koo et al. 2016; Nkonya et al. 2016;). Existing studies on soil health have primarily focused on on-farm combinations of technology adaptation and natural resource management best practices (e.g. composting, mulching, agroforestry) (Koo et al 2016), whereas the off-farm elements of soil health are addressed separately in the body of literature related to community governance of natural resources and regional efforts towards soil and land conservation (reforestation, watershed management, designated conservation areas, etc.) (Robert 2001; Govaerts et al. 2009; Jandl et al. 2011; Keesstra et al. 2016). A more integrated approach that breaks silos of discipline and bridges these lines of work to address both on- and off-farm elements of soil health is needed. As problems have become increasingly interlinked across temporal and spatial scales, we need integrated approaches and systems thinking to seek solutions.

Another example of why an integrated approach is needed lies in the complementarity between sustainable land management (SLM) and other interventions, such as those aimed at irrigation, in achieving sustainable soil health goals and farm productivity growth goals. We recommend that research design better link SLM with other interventions that affect the effectiveness of SLM on soil health. For example, returns to SLM approaches are much lower under certain precarious agro-ecological conditions in the absence of irrigation and soil amendments (Giger et.al. 2015). Mvula and Mulwafu (2018) suggest that the disappointing impact of many investments in soil fertility improvement programmes can be partly attributed to the overreliance on rain-fed agriculture (Chirwa et al. 2008). One of the key aspects of the framework we have presented is the interrelationships among its different elements. There exist trade-offs and synergies in how these relate to one another, and these need to be considered in any research and practice related to soil management.

In their work on gender and inorganic nitrogen, Farnworth et al. (2017) indicate that systemic research is needed on the rates of inorganic nitrogen use on women-managed, men-managed and jointly managed plots, and any other management configurations relevant in the local context. They point out that more evidence is needed on the degree to which nitrogen application differs by management type, the rationale (from the plot holder's point of view) for these differences and how differential application affects plot productivity by manager and by crop; at the same time, the distribution of benefits from differently managed plots needs to be examined carefully. The same can be said for the adoption of soil management approaches and practices more generally.

As this paper has shown, gender relations are complex and nuanced, sensitive to framing and perspective, and likely looks different under different shades of light (i.e., context-specific). Interdisciplinary teams that bring soil health professionals and practitioners with social scientists with experience in gender and socio-economic analyses are needed to provide the necessary richer understanding of how these may influence the outcomes and equity of soil management initiatives.

Investment in data collection

Systemic research depends on systemic data collection. The Farnworth et al. (2017) example given above on gender and inorganic nitrogen highlights the need for a diverse set of data, such as soil biophysical data, gender- and plot-disaggregated data on soil fertility management and other related management, as well as socioeconomic and perception data allowing for assessment of decision-making and benefit distribution.

Biophysical measures, such as key indicators of soil health, when paired with gender-disaggregated survey data on farming practices, asset control, etc., can provide powerful information on the biophysical outcomes of management. Recent analysis by CGIAR's Water, Land and Ecosystems (WLE) research program demonstrates the value of combining socio-economic data with biophysical data over a longer period of time, which is especially important for land management investments that take time to capitalize (Nkonya et al. 2018). Despite the benefits, long term data collection which includes biophysical measures meaningfully matching the socio-economic study unit or subject carries huge costs in terms of financial resources, human resources, and time. Investment in research to significantly lower the cost of such data collection is urgently needed. Recently advancement in remote sensing-based technologies offer great potential to help fulfilling some of the data gaps (Kuemmerle et.al. 2013), though further testing and field validation is needed.

Address underlining conditions and demographic changes

From a gender perspective, it is evident that supporting women's access to a soil management innovation without also addressing the formal and informal structures that hinder their application of this practice or technology will not yield fruit. These structural constraints include insecure access to and control over land, time poverty, inadequate access to productive resources and information, and unequal decision-making power within their household and community, to name a few. A multi-pronged approach, which seeks to lift the multiple constraints that hinder women's adoption of soil enhancing practices and facilitates their capacity (and that of male farmers) to innovate in soil management is needed. Moreover, soil management initiatives must consider the potentially adverse effects certain innovations can have on women farmers if they fail to account for the gendered division of labor, decision-making, and benefits that will underpin their application. Examples provided above of increased in women's workload without commensurate benefits to women are a case in point.

As the gendered conceptual framework clearly indicates, we must take more nuanced perspectives when interpreting the complex and highly contextual relationships between gender and soil management outcomes. We need to keep breadth with the emerging and persistent challenges women face, which impact their productivity and wellbeing. For example, large-scale male out-migration in Nepal has increased the workload and burden of women, whereas an increase in women's authority in household and community decision-making may or may not have been realized and/or benefited women (Sherpa, 2010; Gartaula et al. 2010; Zwaterveen et.al. 2010; Maharjan et al. 2012; Glennie, 2012). Gender and social norms that maintain heavy demands on women's time, limit their economic opportunities, or prevent them from participating in certain activities such as irrigation system maintenance are not easy to shake, yet gradual changes have been noted in various contexts (e.g., Gartaula et al. 2012; Pradhan et al. 2015).

Leverage soil health management for gender equality

Managing healthy soils can contribute positively to several sustainable development goals, including gender equality, rather than compromising them. For example, soil health policies and programs should help challenge, rather than reinforcing, gender norms and conditions that perpetuate inequalities and t marginalization. If soil management interventions are carefully tailored, they can significantly improve women's crop productivity and generate income and wellbeing benefits, including health and food security benefits for women and their households (Lal 2016). This will require a deep understanding of how gender and soil health interact and ensuring that interventions are inclusive and advance the interests of different social groups, especially those which are most marginalized (Marks et al. 2009). We hope that the framework we have presented here can contribute to this ambitious, but critically important endeavor.

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